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ABSTRACT

The Carnegie Foundation commissioned a collection of essays as part of the Carnegie Initiative on the Doctorate (CID). Essays and essayists represent six disciplines that are part of the CID: chemistry, education, English, history, mathematics, and neuroscience. Intended to engender conversation about the conceptual foundation of doctoral education, the essays are intended as a starting point and not the last word in disciplinary discussions. This essay suggests that a number of practices common in doctoral education in chemistry are less than optimal and may be evolving in counterproductive directions. It discusses the need to integrate more professional skills and knowledge into the doctoral program, to reduce the time to degree, and to prepare the next generation of mentors for the academy. (EV)

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CARNEGIE ESSAYS ON THE DOCTORATE

CHEMISTRY

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REFLECTIONS ON DOCTORAL EDUCATION IN CHEMISTRY

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INTRODUCTION

U.S. doctoral education is respected around the world and is increasingly seen as one of the factors in the success of the U.S. in research. Despite this enviable record, a number of studies in recent years have questioned whether or not elements are missing in the Ph.D. program and what should be done to correct any deficiencies.[1] Many of the issues that have been widely discussed in such initiatives as "Re-envisioning the Ph.D." will be explored further in this essay.

To begin, let us examine the essence of the doctoral program – regardless of discipline – shorn of all its trappings.

The nature of doctoral education

Education at any level works best when there is strong motivation on the part of the student, a natural curiosity, an insatiable desire to understand a question that just has to be answered. When this quest is coupled with an informed and inspiring mentor who can guide the intellectual exploration with the appropriate resources, one has an optimum learning environment: Aristotle at one end of the log and Alexander at the other! One might aspire to achieve this goal at all levels of education, but the demands of mass education on the one hand and the complexity and vastness of contemporary knowledge on the other militate against such a lofty ideal. That ideal has, nonetheless, been reserved formally for those who engage in doctoral education. Indeed, graduate education is first and foremost an apprenticeship – an apprenticeship in the art of discovery.

Arguably the essence of the Ph.D. degree is scholarly development that demonstrates creativity, independence of critical thought, and the ability to frame incisive questions about an issue. The purpose of Ph.D. training is to help a student develop certain "habits of the mind," acquire an appropriate array of associated skills, and become the unquestioned expert on some specific topic. This process was spelled out nicely (though perhaps a bit too grandly) a century ago by von Sybel, as reported by Paulsen:

> "But it is essential that the student should become distinctly conscious of the problems of science and the methods by which they are solved; it is necessary that he should employ these methods in a few directions to their ultimate consequences, to a point at which he can say that there is now no one in the world who can teach him anything about it, where he can stand firmly and securely upon his own feet, and can decide according to his own judgment. Such a consciousness of independence achieved through one's own efforts is of inestimable value. It is practically immaterial what the subject of the investigation was which led to this: it is enough that, in one field, no matter how unimportant, dependence upon the school was done away with; the powers

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[1] An extensive bibliography is provided by the program on "Re-envisioning the Ph.D." located at the University of Washington. See http://depts.washington.edu/envision. An excellent introduction to the study can be found in "Re-envisioning the Ph.D.: What Concerns Do We Have?" by Jody Nyquist and Bettina J. Woodford, published by the Center for Instructional Research and Development, University of Washington, Seattle, WA. Most of the contemporary concerns regarding doctoral education in this country are reflected in the material available from these sources.

and methods have been tested with which henceforth every new problem can be attacked and carried to a like conclusion."[2]

There is a remarkable consensus that this general concept constitutes the essence or core of the doctoral experience. To be sure, there are significant differences in expectations, quality, and performance within any given department and between different Ph.D. candidates. That variability becomes even more pronounced as one expands the comparison to different departments, different institutions, and different countries. Standards vary, the quality of the faculty varies, and the cultures of the disciplines vary. Despite this, there seems to be a tacit understanding of what constitutes a well-prepared Ph.D. student. Indeed, it is remarkable that the Ph.D. program, administered by hundreds of thousands of different individuals in a thousand institutions and in the complete absence of any central repository of rules or a cosmic accrediting agency, remains universally recognizable and extraordinarily stable.

This core concept of the Ph.D. characterizes doctoral training in chemistry. It is an abstraction that is never realized in practice, just as the idea of a perfect single crystal is an everyday working model for a chemist even though such an entity is never encountered in the real world. The robust nature of the doctoral model in chemistry suggests a tacit understanding regarding the idealization and importance of the model. We might tread cautiously before recommending any drastic changes in that model. Indeed, the maxim "if it ain't broke, don't fix it" might well be applied to doctoral education in chemistry in this country. By and large, it has been a highly successful enterprise and if left largely intact would not seriously hamper research advances in the field.

However, much has changed in the research enterprise over the last 50 to100 years. A short list of relevant changes might include the introduction of computers, information technologies, and the Internet; globalization of the economy and research; intellectual property as a central focus in academic settings; the changing role of women in society; the growing importance of a diverse workforce; the need for interdisciplinary approaches; the decline of hierarchical structures and growing emphasis on human rights; the nature of funding for research; the changing demographics of the student pool; transformation of many disciplines to a molecular focus, chemistry's traditional arena; changing workforce needs in industry; and simulation as a third arm of research (besides theory and experiment).

These changes, however profound, do not alter either the essence or the purpose of the Ph.D. In other words, the core remains unaffected by the changes. Nonetheless, a number of practices common in doctoral education in chemistry are less than optimal and some are evolving in directions that may be counterproductive. Of these, three are most important to attend to. We need to integrate more professional skills and knowledge into the doctoral program. Serious efforts must be made to reduce the time to degree. And we must address the biggest shortcoming of the field: our failure to prepare the next generation of mentors for the academy.

The strategies proposed in this essay are intended not as rigid prescriptions, but as initial ideas designed to stimulate further discussion and refinement of these key issues.

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[2] Paulsen, Friedrich. *The German Universities and University Study*. tr. Frank Thilly and William W. Elwang. New York: Charles Scribner's Sons, 1906. p. 307-308.

INTEGRATING PROFESSIONAL SKILLS AND KNOWLEDGE

Most of the recent discussions of reform for doctoral education in chemistry have focused on functional improvements that would give new Ph.D.s a more complete repertoire of professional skills. Although professional skills are not the core or essence of the Ph.D., these skills are considered important for all graduates of chemistry doctoral programs, especially those planning to work in industry—nearly 70 percent of all Ph.D.s in the field.

Let's examine a list of potentially "missing elements" in our graduate students' training: need for more training in patent law; improved communications skills, both written and oral; early introduction to the nature of a career in industry; learning to work in teams; counteracting the tendency toward increasingly narrow training; developing an appreciation for economic factors in an industry setting; greater emphasis on safety training; instruction on human behavior and personal interactions; emphasis on strategies for research planning; and greater attention by faculty to their mentoring role.

The list above was compiled from a 1947 study published by the American Chemical Society based on the Committee on Professional Relations' surveys of chemistry department chairs, recent graduates who had taken jobs in industry; and directors of research in industry.[3] The concerns identified more than 50 years ago have a striking similarity to those identified in the most recent discussions of problems in the chemistry Ph.D.[4] Indeed, a current list of desirable experiences and background includes:

- Better training in interpersonal communication
- Better skills in writing and public presentations
- Learning how to work in teams
- Developing skills in technology use
- Focused training in ethics and conflict of interest issues
- Understanding entrepreneurial strategies and technology transfer
- Increasing the breadth of exposure to other fields
- Understanding the need for an international outlook
- Better understanding of opportunities in industry
- Gaining exposure to the economic drivers essential for success in the private sector

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[3] *Chemical and Engineering News*, 25 (1947) 1934-1936, 2010-2013, 2076-2081; *Chemical and Engineering News*, 26 (1948) 166-167.

[4] See "Re-envisioning the Ph.D." and Nyquist and Woodford, cited above. See also "Reflections on Graduate Education" by Marjorie Caserio, *Newsletter of the ACS Younger Chemists Committee*, Fall 2002. http://membership.acs.org/y/YCC/NewsLetter/F2002/OGE.htm and, "How Long Should it Take for a Graduate Student to Get a PhD in Chemistry?" by John D. Roberts in the *Newsletter of the ACS Office of Graduate Education*, v. 1, #1. and letters in response v. 2, #1.One of the arenas where an active discussion of the need for reform of the chemistry PhD program is being carried on is that of the Graduate Education Advisory Board of the American Chemical Society. Further information is available from the Web site: http://www.chemistry.org/portal/Chemistry?PID=acsdisplay.html&DOC=education%5Cstudent%5Cgradoffice.html

Since all of these skills continue to be of significant concern to industry, the primary employer of Ph.D. graduates in chemistry, we should consider what improvements might be made and how.

Some will argue that these are skills and topics that the student should have been exposed to prior to entering the doctoral program. Graduate schools might demand that students be deliberately and systematically introduced to these skills and topics in their baccalaureate chemistry programs, perhaps through new, stand-alone courses and incorporation of these issues into existing courses. However, even if undergraduate programs included exposure to professional skills and knowledge (which will surely be some time in coming), the doctoral students need to address these skills and topics at a deeper, more sophisticated level. Therefore, if we believe that professionals should be more informed on these topics than they currently are it is necessary to develop learning activities on these topics at the graduate level.

Unfortunately, adding to the existing doctoral program can exacerbate one of the field's serious problems: the time to degree. Taking an additional course in a related field to improve breadth, or spending time in another lab (on the same campus, in industry, or in an international setting) requires a commitment of time. However, there are ways to expand training by using time wisely.

For example, training in ethics, conflict of interest, and technology transfer might be accomplished with intense weekend short courses followed by one- to two-hour sessions each quarter involving formal presentations and group discussion. Likewise, developing skills in the newer and emerging technologies may be an area where self-paced or "distance learning" modules could be very effective.[5] Learning more about the work environment in industry, opportunities in entrepreneurship, and the importance of economic factors in all industry programs may well be handled best by a full quarter or semester course in which faculty and visitors from industry provide a series of lectures to inform the students about these issues.[6] Examples of such enhancements already exist at various institutions, and these could serve as models.[7] A major effort underway in the United Kingdom adds new dimensions to doctoral programs to develop professional skills and knowledge.[8] At the end of this essay, Table I suggests a curriculum to develop professional skills and knowledge.

A key issue is whether a department would require student participation or whether it would be voluntary. That, in turn, would depend on how seriously members of the faculty view the

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[5] For example, the recently established NSF Science and Technology Center for Materials and Devices in Information Technology Research plans a series of self-paced learning modules on a range of topics in opto-electronics. See https://depts.washington.edu/stcmditr/. Distance learning modules are increasingly available on the Internet.

[6] A discussion of this issue and a description of one such course offered by Professor Joel Shulman at the University of Cincinnati can be found at http://nextwave.sciencemag.org/cgi/content/full/2002/07/16/6

[7] An example of a program designed to foster more teamwork is provided by The NSF funded IGERT program on Urban Ecology at the University of Washington. They have outlined a novel program that provides graduate students with experience working as teams. Information about the program can be found at http://www.cfr.washington.edu/research.urbaneco/

[8] "The New Route Ph.D." is being introduced in many disciplines across many institutions in the UK. Information can be found at http://www.newroutephd.ac.uk. This new program incorporates many of the elements included in our list of functional enhancements.

need for improvement in these areas or how much pressure they feel from outside stakeholders. As stated at the outset, there is a strong underlying view among chemistry faculty that doctoral education in chemistry is working quite well in the U.S. That automatically will weaken any resolve by a department to introduce enhancements, even if the additional time required on the part of the student is kept to a minimum. The task is made even more difficult if one seeks to reduce the time to degree. By and large, chemistry departments have been relatively conservative in keeping the time to degree from getting too far out of hand. Nevertheless, as argued below, it needs to be shortened. Although we might agree in a global sense that professional skills need more emphasis, this area will probably not receive serious attention until industry as the major employer of chemistry Ph.D.s demonstrates its seriousness by preferentially hiring graduates who have such training.

SHORTENING TIME TO DEGREE

One of two major structural problems for U.S. doctoral programs in chemistry is the time to degree. Like the weather, everyone complains about it, but no one does anything about it, even though in this case we could more readily effect change. Recent data show that the average time to the chemistry Ph.D. is 6.8 years; for biochemistry it is 7.4 (by comparison, the average for engineering is 8.4 years and in the humanities, the time stretches over a decade).[9] Despite chemistry's good record next to other fields, the trend for the past three decades shows a gradual lengthening. This situation has several negative features. First, it tends to discourage some bright students from entering the program because of the long delay in achieving earning status. Second, it reduces the "window of creativity" because students often do not become independent scientists until their mid thirties. Third, it is sometimes an exploitation of the student for the benefit of the program. Fourth, it reduces opportunity for other students, both in terms of access to those programs and in terms of access to financial resources. Fifth, other avenues will develop to train individuals for the workforce as evidenced by the growth in certification programs and the renewed interest in the professional master's degree. At a time in history when we are experiencing a systematic and long-term decline in the number of U.S. citizens entering doctoral programs in the sciences, it is imperative that we re-examine our programs. We are less and less competitive for the best and brightest who perceive that the time to degree (and even time-to-career) in medicine, law, and business is much more predictable, shorter, and more financially rewarding.

What is an appropriate time to degree? Whatever satisfies the essential training program for the student. In other words, if the student could gain the appropriate experience in three years, then that would be the appropriate length of time for the program, not five years or seven years. Those extra years of apprenticeship are serving purposes other than the basic education of the student. Obviously, the skills of the advanced student are a huge advantage in meeting the demands of the sponsored research program. But such extended engagement could be subject to a charge of exploitation. Space does not allow for an exploration of mitigating circumstances (those that might require extended doctoral studies) such as an entering student with inadequate preparation, the student who has to engage in non-dissertation work for much of

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[9] See "Doctorate Recipients from United States Universities: Summary Report 2001," Appendix Table A.-3a. It should be noted that these figures refer to the median time from bachelors' degree to Ph.D. "Registered time to degree" is less by roughly a year in the sciences, and two years in the humanities, largely because of the delay between completion of the B.A. and start of the Ph.D.

the period of doctoral studies because there is inadequate funding,[10] or the student who has begun to unravel an exciting mystery and it would not be sporting to interrupt the chase in midstream. However, even if we accept that there are always exceptions to every rule, most observers acknowledge that the time to degree in chemistry is too long.

Some contrarians might argue that in today's complex knowledge environment it takes five to seven years for a student to be able to make an original contribution to the storehouse of knowledge. The counterargument is that one can set the dial to any chosen degree of accomplishment from zero to infinity. We do not require a graduate student in chemistry to build a synchrotron and solve the crystal structure of the major histocompatibility complex in order to establish that she has the necessary talent to be awarded the doctoral degree. A thoughtful mentor can design problems with various degrees of complexity, each of which can serve as a training ground to develop creativity, independence and the ability to "frame questions." We seem to be able to define bite-sized projects routinely for undergraduate research, for master's theses and for postdoctoral training. Likewise, we should be able to titrate the assigned problem to the appropriate time frame for graduate students. Unfortunately, too often the mentor does not think carefully enough about the scope of the problem assigned to the student and whether it is realistic for a three-year effort. Of course, even in a well-designed program, a problem may turn out to be intractably difficult. An essential part the research is often to establish precisely how difficult the problem really is. However, such projects in particular need to be monitored with special care.

Despite the endless debate one could have about how long the dissertation research should really take, there are models from Europe that can be considered. For example students in the UK are expected to complete their Ph.D. studies in 3 years.[11] Exceptions, though possible, are usually discouraged. To be sure, there are differences in the level of pre-doctoral preparation, but the fact remains that the majority of the students finish in three years. Few would argue that the British Ph.D. is a woefully inadequate preparation for the workplace. The system in Germany is similar: most students are expected to complete their Ph.D. research within three years of the Diplom (roughly equivalent to the U.S. master's degree).[12]

Why, then, is the U.S. time to degree twice as long as in these examples? There are a number of factors; a few are fairly obvious. First, in contrast to the U.S. model, in the UK and Germany, the entire undergraduate experience is essentially focused on the discipline being studied. Second, the U.S. has arguably made a greater effort to open college and Ph.D. programs to a broader cross-section of its citizens than has traditionally been the case in Europe and elsewhere; this means that the range of preparation of those entering Ph.D. program in the U.S. is more variable. There is probably also much greater variability in the level of preparation of students in high schools in the U.S. than in Europe. These factors combined mean that the students enter graduate school with very different levels of preparation. Consequently, many U.S. students

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[10] Some recognition must obviously be given to factors such as financial support. A student who is unsupported for the entire time (an exception in chemistry) or one who has to serve as a teaching assistant during the entire duration of the doctoral work clearly requires more time than students supported either as research associates or on fellowships.

[11] See http://www.hefce.ac.uk/pubs/hefce/2001/01_56.htm and the websites for individual universities.

[12] See http://www.bmbf.de/index.php3 and the websites for individual universities.

will need remedial work and coaching to bring them to roughly the same starting point as their better prepared peers.

Another factor is the nature of research funding in the United States. Grants are made to the faculty member who, in turn, pays the graduate students who work in the lab. To succeed in getting the grant renewed the faculty member has to demonstrate significant progress each year. The degree of progress, of course, depends directly on the quality and experience of the graduate students working on the problems. Clearly, the more experienced the student, the more productive he can be. Therefore, keeping the student for an additional year or two is highly advantageous. It can also benefit the student, because as the student becomes more productive, he produces more quality work and publications, and enhances his chances for recognition and career advancement. In addition, since job opportunities are episodic, the student expands his chances for just the right position by expanding the time frame in which to seek a position. However, the extra two or three years of "service" are not an essential feature of the doctoral program; it is often simply a matter of convenience or a response to funding pressures.

Changing the duration of the doctorate is intimately connected to the duration and nature of the postdoctoral training period. (I turn to the content of postdoctoral positions later in this essay.) Obviously one could arbitrarily divide up today's not uncommon ten-year training period into 7-year doctoral and 3-year postdoctoral periods, or one could have 5-year doctoral and 5-year postdoctoral periods. The economics will obviously be different, but there are other issues more important than the cost to the research program. These funding issues should be re-visited with an eye to a more balanced, effective and shorter program.[13]

How to shorten time to the Ph.D. in chemistry

Should we shorten the time to degree in the U.S.? Yes. Is that likely to happen in the absence of a crisis? Not likely. It would require fundamental structural changes in the way graduate students are funded, in the culture of the peer review system, and in the attitudes at funding agencies and among the faculty supervisors. Should we organize ourselves to achieve such change? Yes. If the universities together with the professional societies (e.g., The American Chemical Society, The American Physical Society, Federation of American Societies for Experimental Biology, The American Association for the Advancement of Science), higher education organizations (American Association of Universities, National Association of State Universities and Land Grant Colleges), the National Academies of Science, foundations, and the federal agencies agreed that this was important for the nation, they could, in short order, set in motion the necessary actions in order to accomplish this goal. This is not a difficult problem; it is a matter of the will to do it.

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[13] At the NSF's "Workshop on the Future of Graduate Education," held in Washington DC, Harvard economist Richard Freeman pointed out that many Ph.D. scientists earn 25 to 30 percent of their lifetime income through graduate and postdoc stipends. This is based on his analysis that the average time to degree in all science fields is 7 years plus 5 years in a postdoc position. When future earnings are discounted at 5 percent, it becomes apparent that nearly one third of the scientist's lifetime income was obtained before he or she got a job. See http://www.ehr.nsf.gov/dge/agendam03.html .

Clearly, such changes would have ramifications that would need to be addressed including the serious matter of sustaining adequate productivity. But those secondary consequences could be handled by a more deliberate postdoctoral program combined with more realistic policies to support technicians and support staff for an individual research group as well as for groups of researchers. Such a strategy when combined with additional means of providing teaching support (now handled almost exclusively by teaching assistants) could also help rationalize the size of graduate programs. The size of graduate programs (in departments with large service teaching loads) under the present paradigm is often strongly influenced by the need for teaching assistants to cover large lower division teaching loads.

The tension over teaching versus research

It may be appropriate at this point to address another serious underlying issue in graduate education: the confusion about the proper role of the faculty member in a research university setting. There is often an ambiguous attitude on the part of new as well as more established faculty about the primary purpose of their professional academic activities. Indeed, one can get into animated discussions about whether "teaching" or "research" is the more important element. Often this discussion merely serves to confuse the mission with the reward structure. In a research university, research is invariably rewarded more explicitly than undergraduate teaching, but this misses the central point. Although research and graduate teaching are complementary like the two halves of a pair of scissors, the primary mission of the faculty member is education—not the production of research results. Fortunately, in many cases, the intense pursuit of a research project serves many of the needs of the student by default by helping her develop creative thinking skills and other scholarly attitudes.

However, if a faculty member does not understand that his primary role is to educate students, then it is easy to fall into the trap of using the student as a pair of hands to ensure that results will flow to justify the next grant proposal. Rather than thinking carefully about how to design a series of increasingly challenging tasks and projects tailored for the aptitudes and background of the student, and how to lead the student to adopt increasingly more sophisticated analysis and problem solving strategies, the mentor may inadvertently simply offer a series of different projects essential to the success of the research program and largely neglect the task of considering how this course of study will help the student develop into a productive and accomplished investigator. The fundamental philosophical distinction described above is misunderstood by far too many. (Fortunately, the intrinsic nature of the research program often channels the student's development along a trajectory that approximates conscious mentoring.) Both the importance of this fundamental responsibility and strategies for achieving it can be communicated and inculcated.

PREPARING FOR A FACULTY CAREER

The second critical structural problem in chemistry doctoral education lies in the failure to provide an integrated and comprehensive training program—graduate study plus postdoctoral work—for those planning on an academic career. There is today a serious mismatch between the nature and purpose of the doctoral degree and the demands and expectations of the academy, a significant employer of those with the Ph.D. degree.

Imagine spending years training an athlete to learn the intricacies of playing football, and then once he finishes playing college ball, assuming that because he is a well-trained athlete he can

immediately be appointed head coach. This is essentially what we do in the academy. Although the responsibility of faculty members goes far beyond mere research prowess, there is no systematic effort to prepare them for the critically important role of being faculty members.

This failure is one of long standing, but it is becoming increasingly unacceptable. In essence, most institutions encourage their new graduate students in the sciences and engineering to get busy on their research topics, in many cases even dispensing with much in the way of formal course work at the graduate level except for any needed remedial work. The reasonably prepared student often immediately begins to identify a research topic and then spends the next four to six years devoted to an intense pursuit of that research program.

Once her research is completed, the newly minted Ph.D. will probably elect to spend a year or two as a postdoctoral fellow in another institution, either expanding her repertoire of skills in the same field or in a closely related field of endeavor. Again, this can be an intense period of focused research activity, sometimes writing papers and maybe even writing some initial proposals to seek research funding. Once that coveted academic job offer is nailed down, the pressure to produce results begins in earnest. Without much time for reflection or preparation, the next stage typically finds the new faculty member developing her first lectures for an undergraduate course, writing more proposals, setting up a lab, recruiting graduate students and postdocs to the research group, and getting oriented to the new career demands. Since, in many cases, the new faculty member will soon no longer be doing hands-on research at the bench, it is fair to say that all the tasks the individual now faces are ones for which she has had no formal preparation. This approach is not optimized to ensure success. Indeed, the mismatch between training and task is glaring.

A program for preparing future faculty

The need for some training beyond the Ph.D. to prepare the individual for the profession of teaching has been recognized for a long time. The best-known example is the German habilitation program. This program was typically a five- to seven-year (or longer) post-Ph.D. apprenticeship in the academic vineyard before the formal "Dr. Hab." was conferred and the candidate was considered qualified to hold a professorial position in the university.[14] The habilitation concept was excellent; the execution left much to be desired. Indeed, somewhere in the distant past a serious commitment to a systematic preparation for the academic role seems to have atrophied, and the habilitation process simply became another formal hurdle to surmount on the way to the coveted professorship. Both the gradual lengthening of the period for the habilitation process and its increasing divergence from its original purpose have recently been addressed by the German government. Beginning in 2002 the Dienstrechtsreform Act will begin to phase out the habilitation process in favor of something akin to the U.S. research assistant professor position (but without the direct tenure path or its equivalent).[15] I would argue that the baby is being thrown out with the bathwater. In particular, might it not have

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[14] See http://www.bmbf.de/index.php3 for general information on the habilitation requirements. Note that the individual could not enter the habilitation program directly upon receiving the Ph.D. but had to have independent employment for two years first. Another excellent source of information can be found at http://www.uni-konstanz.de/struktur/fuf/pulfak/studpol/polpol/habilitation .

[15] Q. Schiermeier, "Breaking the Habilitation habit", Nature 415 (2002) 257-258. For a full discussion in German see "Dienstrechtsreform an den Hochschulen" at http://www.bmbf.de/3992.html

been better to reform the habilitation process by shortening the process from the roughly ten year post-Ph.D. sojourn to two to three years "internship" (inclusive of postdoctoral work)?

Ironically, while Germany consigns its venerable habilitation process to the historical archives, I am suggesting that the habilitation concept—not its structure—should be implemented in the U.S. The fact that there is a problem is recognized on both sides of the Atlantic. As noted above, in the UK, a dramatic change is currently being introduced in part to address a number of the issues through the "The New Route PhD." Although its primary focus is on "functional enhancements" it implicitly contains some elements that could benefit a new faculty member. A more direct attack on the problem has been gestating for more than a decade in the U.S., spearheaded originally by The Association of American Colleges and Universities and the Council of Graduate Schools, and funded by The Pew Charitable Trusts (and more recently by The Atlantic Philanthropies and NSF). This program, called "Preparing Future Faculty" seeks to provide graduate students with some orientation regarding academic careers.[16] (The more recent initiative in chemistry has been led by the American Chemical Society, the Council of Graduate Schools and the NSF.) This is an excellent start. However, it is far too limited both in the time devoted to the task and in the scope of the effort, to serve as an adequate preparation for the academic career. Much more needs to be done, and it needs to be done formally and systematically.

To justify this statement, we need to examine the goals one might identify to properly prepare future faculty. In what follows, I suggest a program during the postdoctoral period, when those planning on an academic career are trained in some of the essential skills for such a career—skills that are now either missing or addressed only in a rather rudimentary fashion.

The elements of a strategy. The process of developing a strategy to address this problem has several parts. First, one must begin by identifying what is missing: in other words, one needs to make an analysis of what one expects new faculty members to know when they begin their academic career and take on the awesome role of being stewards of the discipline.[17] Second, one has to decide on the content and how much time should be devoted to the training program. Third, one has to devise a strategy for providing those learning experiences. And, fourth, one needs to consider other changes in the prevailing culture and funding paradigms that would be required to enable the changes to be realized.

What are some of the topics that a new faculty member should have been exposed to before taking on the weighty role of supervising the development of the next generation of educators? A thoughtful and informed group of experienced educators should be able to construct a list of experiences that would benefit the prospective faculty member. The topics outlined below represent my suggestions by way of illustration. The topics are intended to be suggestive and to stimulate discussion rather than to serve as a recipe.

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[16] See the Preparing Future Faculty (PFF) program description at http://www.preparing-faculty.org/PFFWeb.Contents.htm. The PFF program is pointed in the right direction and represents an important effort in addressing a serious problem. It needs to be expanded.

[17] The term "steward" is an excellent expression for those who serve in the professorial ranks. In practice it may be even more applicable to those mentoring Ph.D. students than to those teaching in community colleges, but it has meaning in both contexts. In my usage of the phrase, I limit it to those in the teaching profession.

1. Education as a profession. As a result of increasing pressure in recent years, many institutions now have brief "orientation" sessions for new faculty in which they are encouraged to participate in "instructional development" tasks. At least this rudimentary effort is an acknowledgement that there is a problem, but the effort is hardly commensurate with the magnitude of the challenges faced by a new faculty member. The entire scope of the "orientation" needs to be changed and a broader array of elements included. The "orientation" needs to begin with a focused discussion of the underlying philosophy that should inform the professional educator. We also need to be explicit about the responsibilities implicit in the role of educator. Maybe we even need to develop something like a Hippocratic Oath for educators.

2. An apprenticeship in teaching. We need to provide some effective training on the practical issues associated with developing and presenting a course in an effective manner. To illustrate, let me recount my own experience. I had the good fortune of benefiting from an experience that provided some of the latter "orientation." I was awarded the Alfred A. Noyes Fellowship at Caltech upon completion of my Ph.D. This unique award allowed me to carry on any research project of interest but it also required me to serve as an assistant to one of the senior faculty members. In my case, I teamed up with Professor Wilse Robinson who was teaching the course in physical chemistry. This experience of working directly with a seasoned educator, giving lectures from time to time (reviewed in advance by Professor Robinson), preparing problem sets and exams, mentoring students, and preparing explanatory and background material, provided a solid foundation for my later teaching responsibilities as a new faculty member at Harvard. I cannot overemphasize how constructive and important that experience was to my future role as a faculty member.

There are other important elements (all too often ignored or taken for granted) that are essential to working effectively in the classroom. These include an understanding of the psychology of students, the role of the mentor, and the utility and fairness of assignments, grading and expectations. Most of the insights graduate students develop on these topics are currently gleaned in classes they take, resulting in serious variability. When the new faculty member then applies that experience in the classroom as a new faculty member the result often leads to considerable confusion and consternation on the part of the students. In short, the typical two-day orientation needs to be replaced with a full year of apprenticeship as an instructor, including a short course that puts the professional role of a faculty member into context.

3. History of the discipline. Most students in the sciences gain virtually no background in the history of their discipline throughout the course of their doctoral work, and precious little as undergraduates. Although the individuals may know a great deal about the trajectory of the particular topic of their dissertation, the broad sweep of the history of the discipline may never have crossed their field of view. Students who are going to be mentors of the next generation of practitioners should be required to spend at least a modest amount of time reading key works that provide an overview of the major events that shaped the development of the discipline. This would take various forms for different disciplines, but some introduction to the topic should be required. For example, in my view, every prospective chemistry teacher should be required to read Lavoisier's *Elements of Chemistry*.[18]

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[18] Lavoisier, Antoine-Laurent. *Elements of Chemistry*. tr. Robert Kerr. New York: Dover Publications, 1965.

4. Ensuring breadth. The focus and intensity of the graduate experience usually limits the student's exposure to the major intellectual challenges of contiguous fields. Especially in this era when nearly all the sciences (and engineering) have shifted their focus to include the molecular level, it is imperative that chemists, of all those trained in technical disciplines, should have a broad perspective of the frontiers of the scientific enterprise. This can be done in several ways, any one of which could be selected as a means of ensuring greater breadth. For example, a postdoctoral student could spend a quarter in another laboratory not directly related to his Ph.D. He could take a formal course in another discipline. There could be organized reading clubs that would systematically explore a range of related topics. I have argued above that such broadening of the educational experience should happen during the Ph.D. program as well, since the issue of "breadth" is also of great concern to industry employers.[19] But it is so critical for effective mentoring, that additional breadth could and should be added for those preparing to be stewards of the discipline.[20]

5. Management and personnel skills. The newly appointed faculty member immediately becomes the head of a "small-business" with responsibility for hiring and supervising "employees," meeting payroll, engaging in advertising and promotion, managing budgets, and so on. Some of these activities will be somewhat familiar to the individual; some of the necessary skills will have been developed informally, in a well-run research group, during the doctoral program. But there is generally no systematic approach to prepare prospective faculty members to function in this arena even though it will be critical to their long-range success. This omission needs to be corrected before they join the faculty. Indeed, one can argue that having such training is much more important for the beginning faculty member than it is for a new employee in industry or a government lab. Why? The reason is that in the latter two contexts the employee normally starts at an apprentice level or as part of a group, and receives appropriate mentoring (and often management training) in the early years. By contrast, the new faculty member becomes a "manager" the moment she is appointed and is expected to have acquired all the necessary management skills magically.[21]

6. Institutional structure and governance. Most faculty members are relatively uninformed about how the institution functions, what the expectations are and what the opportunities for affecting the direction of the institution are. Even an elementary overview of the broader institutional machinery (including grievance procedures and dispute resolution strategies) could go a long way toward simplifying the life of the new faculty member. There is often an unfortunate and insidious culture of antagonism between faculty and administration. This is as

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[19] See http://www.grad.washington.edu/envision/resources/Kaldor.ppt

[20] Indeed, it is surprising that we have not instituted general courses at the graduate level designed for the non-specialist that provide a broad overview of the major intellectual challenges in various disciplines. Maybe this could be considered the tragedy of the intellectual commons: it is everyone's responsibility to do this and so no one does it. One of the most difficult tasks in organizing sessions for AAAS meetings, for example, is to get speakers to present their material in a way that is accessible to the informed layperson. We seem to suffer from a Tower of Babel syndrome that prevents us from conveying the essential ideas in jargon-free language to our colleagues in other disciplines (to say nothing of the public).

[21] In July 2002 the Burroughs Wellcome Fund and the Howard Hughes Medical Institute debuted a four-day summer "Course in Scientific Management," see *Chemical and Engineering News*, 80 (2002) 64, 66. A manual is in preparation. See also Barker, Kathy *At the Helm. A Laboratory Navigator*, Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press, 2002.

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old as humanity and will not disappear. But it is counterproductive, and often the worst excesses arise from simple ignorance and misunderstanding. An introduction that provides a basic orientation to the strategic goals of the institution together with an overview of the challenges an institution faces can create a much more harmonious environment of cooperation and constructive dialog. Well-designed role-playing sessions on selected topics that an administrator has to deal with can be very instructive for new faculty. For example, a simple introduction to indirect costs and how they are used in the institution could prevent a great deal of unhappiness and misunderstanding on the part of the faculty member—both new and established.[22]

7. Tenure and the tenure clock. This issue receives much more attention today than it once did, but it is still often neglected to the chagrin of faculty and institution alike. Especially in the case of women faculty, issues such as pregnancy leave and extending the tenure clock are important considerations and need to be clearly addressed and understood at the outset.

8. Ethics, conflict of interest, and sensitivity training. Increasingly the varied cultural backgrounds of our new faculty create significant unevenness in both the understanding and application of key practices in the academy. Issues of sexual harassment, conflict of interest, sensitivity to those of different cultures, ethical behavior in relationships with co-workers and students are increasingly a source of conflict and even legal action. Ensuring that new faculty members are sensitized early on to these issues and the rules that govern them can prevent grief later.

9. The importance of diversity. This topic is obviously on everyone's mind these days. But that does not mean that individual faculty have a well developed sense of the critical role they can play as role models, as recruiters of minority and female candidates, and as members of a community with an obligation to further the cause of diversity. A well-crafted training session on this topic could have very salutary affects.

10. Leadership skills. Some faculty members are born leaders and others have to learn. Those in the latter category should not be left to struggle on their own for years before they develop some basic skills in this area. Unfortunately, that is the norm. It is ironic that universities, whose business is education, provide virtually no training for their faculty. This failure is most glaring when it comes to appointing a hapless faculty member to the position of chair of the department, or associate dean, or dean or other administrative position. This behavior is in sharp contrast to the practice at many major companies.[23]

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[22] "A Primer on Facilities and Administrative Costs" by Alvin L. Kwiram, published by the Office of Research, University of Washington, 2001. This publication provided first-hand experience in the importance of effective communication between the faculty and administration. See http://www.washington.edu/research/gcs/gim/gim22a/html.

[23] For example, many academic institutions do not even have a list of resources they can refer their administrators to for training programs in management, leadership and related topics. This became very clear in a special workshop for new Vice Provosts and Vice Chancellors for Research sponsored by the Council on Research Policy and Graduate Education. For more information see http://www.nasulgc.org/councils_research.htm where the CRPGE Workshop on Research Administration outlines discussion topics that included training opportunities in management and leadership.

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There are tried and tested techniques that can help develop leaders, and such training would be beneficial especially since each new faculty member is expected to become a leader of a team immediately. In a broader context, each institution expects the individual to become a leader in some sector of the discipline, however limited. Despite this expectation, there is no provision in general to help a faculty member develop such skills. Again, the situation is often quite different in industry where ongoing training opportunities are often provided for staff.

11. Grantwriting. One of the major challenges for any new faculty member is the need to win funding for her research through competitively won grants. It is distressing to see how many faculty members do not have the skills to write a clear and compelling proposal and how much valuable time faculty lose by not knowing about sources of funding, how to work with program managers, and how to stay informed of non-traditional sources of funding. Doesn't it make sense to try to provide some basic training for such an essential activity?

12. Regulatory and compliance issues. These have grown in complexity and numbers in recent years to the point of numbing the senses. However, since in some cases there are now actually criminal penalties for violations, it is imperative that some introduction to these issues be presented early and forcefully. Managing budgets and working with the institutional accounting system could form part of this topic. Again, the situation in the academy is not the same as in industry: for all intents and purposes, as noted above, the new faculty member is a CEO the minute he assumes the position of assistant professor, whereas the new industry employee typically has time to learn the ropes as an apprentice in a group. In the academy, there is neither mechanism nor time for learning all the needed skills on the job and no leeway to make serious mistakes.

These dozen topics are intended to provide an example, and are not intended in any way to be definitive or to suggest that these are of equal priority. Obviously, some of the relevant skills are picked up in an informal way in the course of the doctoral and postdoctoral work, and in some cases particularly conscientious mentors (and fortunately, there are many of these) will do more than discuss the matter casually in group meetings. But there is no systematic program to provide the new faculty member with the general context of the professorial role, the cultural expectations of the academy or, not least, an adequate sense of the importance of this role.

The topics might also vary somewhat depending on the eventual career choice—whether in a top-ranked research university or in a four year college or at the community college level. But regardless of the institution, it would be hard to argue that the kinds of skills outlined are not essential to a successful career. At the end of this essay, Table II provides a sample course of study.

If one were to accept the argument that some selection of topics such as those outlined above merited greater formal attention than they currently receive, how much time should be devoted to such matters? What would be some of the elements included in the program? Following are a few examples or how this might work during an ideal postdoctoral appointment:

- At a minimum, the prospective faculty member should spend one academic year as a teaching apprentice working with a senior faculty member who has a demonstrated track record as an excellent teacher. This activity should involve a regular undergraduate course (not a lab course, or seminar course). The senior faculty member,

chosen from among those known to be effective teachers, would be expected to serve deliberately and systematically as a mentor to provide a series of teaching experiences with increasing responsibility and independence. The elements to be included in that process should be determined by the collective judgment of the department which would set general guidelines. These responsibilities of the new Ph.D. would probably require about 10 to 20 hours per week.

- During the summer before the first academic year, the postdoc could take an intensive four week course on educational philosophy, general concepts of pedagogy, the balance between research and teaching, teaching via lecture versus teaching via inquiry methods, the profound responsibility of mentoring the next generation of students, the use of technology in teaching and so on.
- A one-term course on the history of the discipline. This could include readings from closely related fields together with case studies of major advances in the field including selected Nobel Prize achievements. What strategies led to success for one scientist and failure for another? Are there common themes that characterize notable achievements? What constitutes a significant strategy in pursuing new understanding? Can one learn from the work of those who have been successful in defining the right question? What are the relative merits of a strategy that focuses on a major problem and tries to solve it by whatever means, and the strategy of developing a new experimental method and then seeking to apply the method to important problems.
- A one-term exposure to increase breadth. This could be a course, work in another lab, or an intensive and formal "journal club" activity.
- A one-semester course on management skills and leadership training. This should not just be handed off to the Business School but could be done productively in partnership with the Business School, and it could be done for candidates in all technical disciplines (at least those with significant emphasis on sponsored research programs). The major focus of such a course should be on leadership training, time management, interpersonal communication, dealing with difficult colleagues, and so on. It could also include elementary accounting and budgeting principles as well as an overview of regulatory and compliance issues.
- An intensive summer program (two weeks) devoted to issues of diversity, ethics, conflict of interest, cultural sensitivity and related topics.
- A year long seminar (one hour meeting a week with "homework") on grantwriting including the actual preparation of proposals, development of writing skills, and understanding the funding environment and strategies. This could also include an introduction to strategies for dealing with the media, fostering the public understanding of science, and communicating across disciplinary boundaries.

The time commitment for the above activities would be roughly half of the available time, or the equivalent of a one-year internship spread out over a two year (minimum) time period. (Obviously, an individual could spend additional time as a postdoctoral student, but only the first two-year stint would have the special internship character.) The rest of the time would be available for research activities.

Some will argue that this represents a lot of make-work that the bright student does not need and would pick up automatically. Reality suggests otherwise as many a department chair (as well as many new faculty members) will testify. And although the bright student may pick up some of this over time, it can be argued that the actual time spent in the self-taught mode may actually be greater than if done in a more organized and systematic manner. That is, after all, the essence of teaching. Further, it should be kept in mind that this is not an activity carried out during the doctoral period. And it is not done after the individual becomes a member of the faculty. It is part of the postdoctoral training period and only for those who plan an academic career. The total time from bachelor degree to first academic appointment ("time-to-career") would be six to seven years (four for the shortened Ph.D. and two to three for the postdoctoral period), which is roughly the period now consumed for the Ph.D. alone.

How would such a program be implemented? One way to approach this task is to consider that most prospective faculty members, at least in the sciences, engage in postdoctoral work before beginning their academic careers. Could one devise a program that would be part of such postdoctoral training for those planning to go into the academic profession? One could image generic courses for all (or most all) disciplines within an institution (which could even be taken by those not in postdoctoral positions; that is, by those doctoral students in the humanities who plan to go into teaching). A course on the history of the discipline would have to be more discipline specific although it would not hurt to have such a course cover several related fields (e.g., physics, chemistry and materials science) with the reading selections modified accordingly. Alternatively, one could have intensive summer programs at selected institutions on a cooperative basis.

If prospective faculty members took two or three courses during the period of their postdoctoral experience (or before assuming their professorial role), and in addition spent some internship time with a seasoned administrator or a teacher in a course, it would have a significant impact on their understanding of their role and responsibilities in mentoring the next generation of professionals.

What other changes would be required? One of the key questions is how this would be paid for. At the present time, roughly 45 percent of all Ph.D.'s in chemistry go on to a postdoctoral position. Most of these positions are paid for by the federal government.[24] However, less than half of the postdocs will go on to regular faculty positions. Therefore, the increased "cost" to the government of supporting this educational internship would be roughly 15 to 25 percent above what the government is paying now for postdocs (which is only a fraction of the total research support). Hence, the impact on the total research budget would be less than five to ten percent. This expenditure would be entirely appropriate for the federal government, first because in would be the easiest way to manage the program, and second because graduate education has largely become a federal enterprise. In the context of the proposed doubling of the NSF budget over the next five years (and the stated goal of increasing the salary levels for postdocs), what better investment than to build into that increase a dramatic improvement in the training of the next generation of stewards of the disciplines?

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[24] See "Doctorate Recipients from United States Universities: Summary Report 2001," Appendix Table A.-3a

There would, of course, be an added cost to the Ph.D.-granting universities in order to mount the courses and training programs outlined above. That could be considered the institutional "match" for the federal investment. In reality, the added cost would not amount to more than the teaching load of one faculty member (since many of the programs outlined above can be distributed across multiple departments).

Is this too high a price to pay? And would such a program just degenerate into make-work and become sterile and oppressive? Of course it could, but it need not. Its vitality would depend entirely on the attitude of the departments on the one hand and the commitment of the students on the other.

In this connection, consider the educational process in medicine. After four years, the medical student is considered to have mastered the basics of medicine. Traditionally, this has been followed by a one-year internship designed to facilitate the transition to a formal medical practice. But for those who are going to become serious practitioners in a specialty, an extended residency program is required. (Usually we prefer to be treated by a specialist who has had such training.) Alternatively, the proposed program for future faculty could be compared to the M.D./Ph.D. program which, though very demanding, is not wanting for applicants.

Is the preparation of our future faculty who will teach the next generation any less important than what we expect of our medical caregivers? Are we not prepared to specify merely a one-year "internship" for future faculty as the minimum investment on behalf of our students? Since the success of our future faculty—and our discipline— depends on the degree to which they do these tasks well, this is where our institutions should invest the greatest energy. Such a formal program of preparation could become one of the most effective means for reforming the Ph.D. for those who plan to become educators and "stewards of the discipline." The continued neglect of this task should be deemed unacceptable.

TABLE I

Suggested "enhancement curriculum" for Ph.D. programs in chemistry

Topic	Year one	Year two	Year three	Year four
Ethics		Q 1		
Intellectual property and technology transfer	Q3			Q4
Interpersonal communication	Q4			
Proposal writing			Q3	Q1, Q3
Team work	Q1			
Interdisciplinary breadth			Q1-Q3	
"Propositions"		Q2	Q2	Q2
Careers in industry		Q4		Q3
Technology and tools	Q2	Q3		

NOTES: Q = academic quarter

The first three topics above would be generic training programs (applicable for all departments) handled by the central administration (e.g., Graduate School, Office of Research, Technology Transfer Office). The next three would be handled jointly by the central administration and an individual department. The last three would be a departmental responsibility.

"Propositions" refers to a program requiring the student to present an original proposal for research and defend it to the faculty and students; the students should do this in each of three years, with proposals at increasing levels of sophistication and expectation. Except for activities represented under "Interdisciplinary Breadth," most of these topics would be covered as short courses or monthly seminars, not regular three-credit courses.

TABLE II

Suggested curriculum for a postdoctoral future faculty program in chemistry

Topic	Summer one	Year one	Summer two	Year two
Philosophy and pedagogy	one month			
Teaching apprenticeship		two to three terms*		
History of the discipline				one term
Increased breadth				one term
Management skills	one month			
Diversity and ethics			two weeks	
Grantwriting	two weeks	monthly		monthly

**A term could either be a quarter or a semester, as appropriate. The 2- to 3-term teaching apprenticeship thus represents one academic year.*

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